A 45-years journey within the reproductive brain of fish

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Highlight:

This article summarizes the scientific itinerary of Professor Olivier Kah from 1975 until 2019. In particular, it highlights his main contributions in the overall scientific context of the time and insists on the major steps of his scientific itinerary and the important choices that had a major impact on his career. It also highlights a number of mentors and collaborators who have influenced his technical and conceptual choices.

This paper is dedicated to the memory of Professor Roland Billard.

Key words: teleosts fish; reproduction; hypothalamus; pituitary; dopamine; GABA; serotonin; GnRH; neuropeptide Y; estradiol; glucocorticoid; estrogen receptor; aromatase; cyp19a1b,; goldfish; rainbow trout; sea bass; zebrafish;

Abstract

This article summarizes the scientific carrier of Dr. Olivier Kah, currently emeritus research director at the National Center of Scientific Research (CNRS) in France. Olivier Kah partly grew up in Africa where he developed a strong interest for animals. He studied biology in Paris and Bordeaux. He next received his PhD at the University of Bordeaux en 1978 and his Doctor of Science degree in 1983. He joined the CNRS in 1979 until his retirement in 2016. Olivier Kah dedicated his carrier to the study of reproduction, in particular to the roles of brain neuropeptides and neurotransmitters in the control of the reproductive axis in vertebrates, mostly fish. More specifically, Olivier Kah was specialized in the use of morphofunctional techniques that he implemented to the study of the organization of the hypothalamo-pituitary complex. He was also interested in the steroid feedback and studied intensively the expression and regulation of estrogen and glucocorticoid receptors in the rainbow trout and the zebrafish. In the last 10 years, Olivier Kah's team focused on the expression and regulation of aromatase in the brain and established that aromatase expression is restricted to a unique brain cell type, the radial glial cells, which serve as progenitors during the entire life of fish. He is also interested in the impact of endocrine disruptors using the zebrafish as a model and recently his team has developed an exquisitely sensitive in vivo assay to screen estrogenic chemicals on zebrafish embryos.

In a scientist's life, it is not every day that you have the opportunity to write a slightly different paper where you can talk about science, but in the context of your own life and experience. So, instead of writing a classical review article, where I would repeat what has already been said either by me or by others, I will seize the opportunity of this Special Issue to share with you some of my memories, some of the reasons that took me on the path of fish Reproductive Endocrinology and some of the driving forces that dictated my scientific choices and conduct throughout my career with the hope that this will inspire the new generation.

Decisive Southern imprinting

During the 60s, my family and I lived in Madagascar and we used to spend the summer holidays (winter down there) on a beach, named Orangea, at the exit of Diego-Suarez Bay (today Antsiranana Bay) in the very north of the island. The place used to be a large military training field with just one house that was lent to us for the wintertime. There was nobody there, just us and hundreds of lemurs and chameleons, not much to do: no TV, no computer, nor any cell phone (not even a regular phone). But, luckily I was able to use an abandoned canoe and, paddling around, I discovered that there was a magnificent coral reef not far from our white sandy beach, devoid of any plastic. From then onwards, I spent most of my days snorkeling, looking at colorful fish and collecting shells. This was a kind of paradise for a young biologist and these few months each year in Orangea strongly reinforced an already well-developed interest for animals in general and fish in particular. Naturally, later, I studied biology, first in Paris next in Bordeaux, and it does not come as a surprise that when I had to pick a lab for my master degree, I chose the only one that was working on fish at the University of Bordeaux.

Moving up from the gonads to the brain/pituitary complex

The subject that was assigned to me was about the control of vitellogenesis in *Gambusia sp.*, a close relative of the guppy introduced in the south of France to fight malaria. Although this was

an interesting ovoviviparous species, I had in fact very little interest in spending my life sectioning vitellogenic ovaries from this tiny mosquitofish. Thus, very rapidly and despite the fact that my lab was absolutely not specialized in neurobiology, I decided to move up from the ovary to study the relationships between the hypothalamus and the pituitary. We have to remember that, at this time, there was a lot of excitement about the control exerted by the brain over pituitary functions. It is in 1977 that Roger Guillemin and Andrew V. Schally received the Nobel Prize for "their discoveries concerning the peptide hormone production of the brain" (Matsuo et al., 1971; Burgus et al, 1971). In the fish, virtually nothing was known about hypothalamic functions. In those days, no one knew that the key factors controlling reproduction in vertebrates were highly conserved, that fishes shared 70% of genome identity with humans and that teleost fish experienced three rounds of whole genome duplications. No one was considering that informative molecules of vertebrates were inherited from invertebrates. Just for an example, one day, while explaining to a skeptical renowned dopamine specialist that I was trying to reveal dopaminergic structures in the brain of a fish, I was told: "So! Fish would have dopamine, how interesting!" A similar anecdote also happened later about serotonin. In fishes, people like Edward Donaldson (Donaldson, 1971), Bernard Breton (Breton et al., 1972), David R. Idler (1975) and Elisabeth Burzawa-Gérard (Burzawa-Gérard, 1971) were trying to purify gonadotrophins. My heroes at this time were also among others Francis Knowles, Lutz Vollrath (Knowles and Vollrath, 1965), John Ball (Batten and Ball, 1977), Ernest Follenius (Follénius, 1970), Madeleine Olivereau (Olivereau, 1976) and of course, Richard E. Peter.

Due to the limited number of techniques that where available to me, basically classical histology and electron microscopy, I soon became an "expert" in hypophysectomy and pituitary grafting, a procedure that was by this time used to investigate if the brain exerted a positive or negative effect on pituitary functions. Believe it or not, I was able to complete the surgical procedure in less than a minute. Several weeks or months after surgery, I would dissect the grafted pituitary and perform either classical histology or electron microscopy. At the same time, we would of course look at control pituitaries that had not been grafted. This is how I became familiar with

the ultrastructure (and the beauty) of the teleost pituitary, not only in the mosquitofish, but also in the European eel and in some Mugilidae (*Chelon labrosus* and *Mugil cephalus*) that were studied in the lab in collaboration with Madeleine Olivereau. In early 1977, while working with Pascal Chambolle, we discovered that in some individuals grafted for several months, the pituitary was able to stimulate the reproductive axis and turn on vitellogenesis. This finding was quite a surprise given that, at the time, grafting the pituitary in various locations ultimately caused inhibition of reproduction in fish. These surprising results were presented in September 1977 at the first ISFRP (International Symposium on Fish Reproductive Physiology; Chambolle et al., 1978) organized by the late Roland Billard, Bernard Breton and Alex Fostier in Paimpont in France. This was my first scientific meeting and a very memorable one for several reasons. Of course, Professor R.E. Peter was there, with his impressive voice and stature, and I was introduced to him, although I could hardly speak any English at this time and I was too shy to say anything anyway. Later, after having published his outstanding paper on the existence of a gonadotropin-releasing inhibiting factor in the goldfish (Peter and Paulencu, 1980), Dick Peter once told me that our report in Paimpont made him fear that we could also have thought of an inhibitory factor. It was of course not the case.

In the mean time, I spent countless hours looking at mosquito fish pituitaries on the electron microscope and this is how I became familiar with one of the peculiarities of certain teleosts, i.e. the direct innervation of the anterior lobe of the pituitary. After a few months, I was able to recognize the different cell types mainly based on the aspect of their secretory granules and I started to study the innervation of the different lobes. During this work, I received strong support from a number of people in particular Drs. Jean-Etienne Surlève-Bazeille, Pierrette Dubourg and Pascal Chambolle (Kah et al., 1979). This is the time when I was collecting pictures of synaptic-like contacts between nerve endings and anterior pituitary cells, something you don't see in other vertebrates that have a hypothalamo-pituitary portal system. What is it still unclear is that, in some species for example in eel or salmon, there is no direct innervation of the anterior lobe, so that no one knows how hypothalamic factors reach the target cells. In a recent work using transgenic zebrafish expressing

multiple variable fluorescent proteins in gonadotrophic and GnRH cells, as well as in blood vessel cells, it has been shown that GnRH reaches the majority of Lh cells through an intricate vasculature network populating the entire pituitary (Golan et al., 2015) but, without electron microscopy, it is difficult to conclude so that the question remains largely open.

In parallel, I started to study the aminergic nuclei in the hypothalamo-pituitary complex in the mosquitofish with the help from a CNRS researcher working in a neighboring lab, Dr. Alain Verna, an outstanding histologist and cytologist, who taught me how to use the tricky Falck-Hillarp method to detect monoamines in biological tissues. This is how I started to work on the hypothalamus and developed a strong interest for chemical neuroanatomy. At this time, the brain of fish was kind of a black box but, fortunately, in 1975, Dick Peter had published two brain atlases in the goldfish (Peter and Gill, 1975) and the killifish (Peter et al. 1975), allowing me to sort of figure out my way in the black box. I still remember with emotion my first results and my fascination for the fluorescence emitted by neurons and fibers, in particular those of the so-called paraventricular organ of the mosquitofish. These tiny structures surrounding the lateral and posterior recessi of the hypothalamus have received a lot of attention due to their high content in dopamine and serotonin (Kah et al., 1978). However, their precise projections and functions are still a total mystery but, in any case, these structures send little fibers, if any, to the pituitary.

Flying to the Far West, one of the best things that happened to me

In January 1979, having defended my University thesis, I was “lucky” enough to be appointed by the French National Center of Scientific Research (CNRS), but under the condition that I would go away for a postdoc in an English-speaking country for at least one year. This was a really wise requirement that had a major impact on the rest of my career. Indeed, in those days, virtually no French scientist could speak proper English and most of them would still publish in French with the result that their papers were not accessible to the international scientific community. A journal like GCE would still accept manuscripts in French, and I myself published two or three at this moment, but this did not last long.

I asked Dick Peter whether he would take me in his lab to study the origin of the pituitary innervation using the brain lesioning technique developed in the goldfish and he said… YES. Today, some 40 years later, I think that the opportunity to learn the English language in total immersion in the outstanding environment of the Peter's lab was a unique chance that was offered to me. In Edmonton, I met many young scientists, most of whom are now notorious scholars, people like Norman Stacey, John Chang, Alice Hontela, Ann Kyle, Harry Cook and Lin Haoran (Figure 1), my tennis partner. Later, I came back to Edmonton, in 1987 for about four months and in 1989 for one year. This is how I met other members of the "Edmonton connection" like Joseph Dulka, Kei-Li Yu, Hamid Habibi, Glen van der Kraak, Vance Trudeau and many other scientists. In Edmonton, Dick and I started to make chemical lesions in the hypothalamus using monosodium glutamate and then I would look at the pituitary innervation using an electron microscope to identify degenerating nerve endings. We had some success, but the results were not so easy to interpret because we were also lesioning fibers of passage (Kah et al., 1983).

Developing an appetence for microscopy

After one year, in July 1980, I flew back to France and I joined the laboratory of Professor André Calas in Bordeaux (Figure 2). André Calas is an expert in morphofunctional techniques such as radioautography, immunohistochemistry, neuronal tracing or in situ hybridization and he was also trying to apply all of these techniques at the electron microscope level (Calas et al., 1974). Each year, André organized a course on the use of these methodologies and by participating, I had the chance to meet many experts, but also many students and scientists coming over to take the course. At their contact, I developed a strong interest for these powerful techniques that I tried to implement in my own research dedicated to the study of the morphological substrate of the neuroendocrine control of pituitary functions.

Under Professor Calas's supervision, I studied the innervation of the pituitary in the goldfish and this is how we could demonstrate, using radioautography and immunohistochemistry at the

electron microscope level, the existence of many GABAergic and dopaminergic fibers contacting gonadotrophs identified on the same preparation using double staining immunohistochemistry and colloidal gold particles (Kah et al., 1986). I should add that, in the early 80s, it was considered very difficult, if not impossible, to develop antibodies against very small molecules such as cAMP or dopamine, considered as not sufficiently antigenic. But, we highly benefited from the first antibodies developed against GABA, glutamate, taurine or dopamine by Dr. Michel Geffard, also working in Bordeaux, and serotonin by Dr. Harry Steinbusch from Maastricht University in the Netherlands. Using these antibodies and also the Falck and Hillarp technique, I could study the organizations of dopaminergic (Kah et al., 1986, 1987) and serotoninergic structures (Kah and Chambolle, 1983). In particular, we could show that there was a group of dopaminergic neurons in the anterior ventral preoptic region and a preoptico-hypohyseal dopaminergic pathway, in agreement with the hypothesis developed by John Chang and Dick Peter (Chang et al., 1990) that dopamine, possibly originating from the anterior preoptic area, was a potent gonadotrophin release inhibitory factor in the goldfish. In collaboration with Dick Peter and Joseph Dulka, we could show that destroying the anterior preoptic area caused the disappearance of dopaminergic fibers in the anterior lobe of the pituitary (Kah et al., 1987). At this stage, I should stress that the first aminergic structures ever observed with antibodies to dopamine were the cerebrospinal fluid-contacting neurons of the paraventricular organ of fish that played a key role in the development and validation of antibodies to dopamine (Geffard et al., 1982; 1984).

In 1993, in collaboration with the late Isabelle Anglade, I achieved one of my old dreams, which was to identify all hypophysiotropic regions of the brain. After implanting into the goldfish pituitary a tiny crystal of the newly introduced compound DiI, a fluorescent lipophilic cationic indocarbocyanine dye that can travel along the cell membranes of fixed tissues, we could map most, if not if not all, neurons projecting into the pituitary (Anglade et al., 1993). When we obtained the first results, Isabelle and I spent the whole night taking pictures on the fluorescence microscope. The technique worked beautifully and we could even label isolated neurons in the olfactory bulbs

and ventral telencephalon, most likely corresponding to GnRH3 neurons. Still with Isabelle Anglade, we obtained very similar results in rainbow trout but they were not published, except in her thesis.

The endless GnRH saga

One of my main interests has always been on GnRH neurons with special focus on the organization of GnRH-systems and characterization of GnRH-receptors. In the early 80s, I contacted one of the pioneers of immunohistochemistry, the late Professor Maurice P. Dubois who actually developed the antibodies that were used for the first studies on GnRH systems in the early 70s (Leonardelli et al., 1973). He was kind enough to provide me with a small aliquot of GnRH and somatostatin antibodies. This is how I saw my first GnRH immunofluorescent neurons and published my first papers using immunohistochemistry (Kah et al., 1982, 1984). But later, in collaboration with Bernard Breton and some chemists in Bordeaux, we could synthesize the newly characterized salmon GnRH (Sherwood et al., 1983) and make good antibodies against this peptide (Breton et al., 1986). It is with these antibodies that I realized the first detailed mapping of GnRH neuron distribution and projections in the brain of the goldfish (Kah et al., 1987). In common with a lot of the GnRH antibodies used later in many studies, this particular antibody did not only recognized only salmon GnRH, but also chicken GnRH-II. Here, it is interesting to recall that the first immunohistochemical localization of GnRH ever made was in the brain of the guinea pig (Leonardelli et al., 1973) that, ironically, does not express the classical mGnRH, but a unique variant (Tyr^2-Val^7-mGnRH). This problem of the cross-reactivity with other GnRH variants became critical when a third GnRH peptide was discovered in perciformes (Powell et al., 1994) making it difficult to study the organization of three independent GnRH systems in the same brain. Later, within the frame of a European project we developed antibodies, not against the GnRH decapeptide, but against the GnRH-associated peptide (GAPs). Using this strategy, in collaboration with Yoni Zohar, Nilli Zmora, José-Antonio Muñoz-Cueto and Abigail Elizur, we obtained the first

detailed mapping of three GnRH neuronal systems expressing the 3 different variants in the brain of the sea bass (Gonzalez-Martinez et al., 2002). At that time, quite a bit of wrong information was published due to the use of poorly characterized antibodies and the lack of appropriate controls. A similar strategy, i.e. to develop antibodies against a fragment of the pro-hormone, was later used successfully to obtain specific antibodies to the closely-related Kiss-1 and Kiss-2 in zebrafish and sea bass (Servili et al., 2011; Escobar et al., 2013). Today, after years of research on several species expressing different variants, it is clear that fish express two or three GnRH variants that arose during the 1R and 2R duplications and associated gene losses. The sites of expression of these different variants, their origin, and their projections have been established as well as the distribution of some of the corresponding receptors although there is still quite a bit of work to be done in this area (Kah et al., 2007; Kim et al., 2010; Tostivint, 2011; Dufour et al., 2019). What is still unclear is the function of these different variants in fish and for more detailed information the readers can refer to excellent reviews (Umatani and Oka, 2019; Dufour et al.,2019).

Moving north opens new horizons

In 1995, I was asked to join and head a CNRS team based at the University of Rennes 1 where Professor Yves Valotaire was leading a group working on the molecular mechanisms underlying vitellogenin synthesis in the rainbow trout. These people were among the first to use molecular biology techniques in France. I had very little knowledge of it, but I knew that molecular biology was going to be absolutely essential for any research including mine. I was wise enough to take the right decision and to move north to Rennes. There, I was able to learn the basics of molecular biology and I initiated a fruitful collaboration with an excellent molecular biologist Dr. Farzad Pakdel who, together with Yves Valotaire, actually cloned the first estrogen receptor in fish (Pakdel et al., 1990) and was a pioneer in the field of endocrine disruptors (Flouriot et al., 1995; Petit et al., 1997). I learnt a lot from these people and I am very grateful to them. Farzad Pakdel had developed antibodies to the estrogen receptor alpha (now *esr1*) from rainbow trout (Pakdel et al., 1994), which allowed us to perform the first, and unique, mapping of esr1 in the brain and in the

pituitary of a fish (Anglade et al., 1993). We also characterized and studied the expression of the three estrogen receptors in zebrafish (Menuet et al., 2002), however, unfortunately, despite several attempts, we could never succeed in developing antibodies.

European projects boosted the research

Thanks to the panel of techniques we had in hands, I was invited to join well-funded European projects, the first one coordinated by the late Professor Niall Bromage, an outstanding scientist and excellent colleague. This is how, with David Mazurais, we cloned several melatonin receptors and clock genes in the rainbow trout and reported for the first time their sites of expression in the brain of a teleost fish (Mazurais et al., 1999, 2000). Other Europe funded projects were coordinated by other excellent scientists such as Professors Silvia Zanuy (GnRH), Geir-Lasse Tarranger (Pubertiming), Thrandur Björnsson (Lifecycle) or David Vaudry (Interreg). In total, I was able to participate in a dozen of European projects and this had of course a considerable impact on resources and research activities in my lab. I was able to hire postdocs and students, interact with many European laboratories, participate in the project meetings, and take my collaborators and myself to international conferences. I also coordinated the REPROFISH European project that aimed at analyzing the state of European research in fish with the ultimate goal of improving European fish farming. This initiative was at the origin of a state-of-the-art report sent to the European Commission (I don't know what they have done with it), but also of the Special Issue of General and Comparative Endocrinology dedicated to fish reproduction (see Kah, 2010).

Fruitful encounter in the Far East

In 1997 and 2003, I was invited to participate in meetings organized by Professor Ching Fong Chang in Keelung (Taiwan). On these occasions, I met Professor Bon-Chu Chung from the Academia Sinica in Taipei and we discovered that we had similar interest in aromatase B, the product of the *cyp19a1b* gene. This was the starting point of an interesting story. In particular, Sok-Keng Tong, a student in Professor Chung's lab, had developed a transgenic zebrafish expressing

GFP under the control of the *cyp19a1b* promoter. Sok-Keng came to my lab and with the help of several antibodies that we had developed, we could show that this line perfectly recapitulated the expression of *cyp19a1b* in the brain (Tong et al., 2006). The report that the brain of fish exhibits between 100 and 1000 times more aromatase activity than the brains of other vertebrates goes back to 1978 (Callard et al., 1978). It took more than 20 years to get some insights into where is aromatase expressed in the brain of fish and why its expression and activity are so strong, in particular in sexually mature fish. It is now clear that *cyp19a1a* and *cyp19a1b* arose from the teleost specific whole genome duplication (3R) and evolved through subfunctionalization (Jeng et al., 2012; Zhang et al., 2015; Dufour et al., 2019). Several neuroanatomical studies based on in situ hybridization, immunohistochemistry and transgenic zebrafish have largely documented the fact that c*yp19a1b* is essentially, if not exclusively, expressed in radial glial cells (RGC), a unique cell type that is largely present in the developing brain in all vertebrates and persists throughout life in teleosts (Forlano et al., 2001; Menuet et al., 2003, 2005; Tong et al., 2010; Jeng et al., 2012). Furthermore, we demonstrated that these cells are progenitors and responsible for the constant growth of the brain in adult fish, which raises the question of what is aromatase B doing in brain stem cells (Pellegrini et al., 2007). Another unique feature of *cyp19a1b*, at least in the zebrafish and some other species such as the rainbow trout (Menuet et al., 2003) or the eel (Jeng et al., 2012), is its exquisite sensitivity to estrogens. In most species, the *cyp19a1b* promoter carries a functional estrogen responsive element (ERE) that is responsible for the high expression of *cyp19a1b* in the brain of sexually mature fish (Menuet et al., 2005; Le Page et al., 2008). As a result, exposing fish to estrogens or aromatizable androgens (Mouriec et al., 2008) turns on a positive autoregulatory loop whose functional significance is still open to speculation (Diotel et al., 2011). Interestingly, in the hermaphrodite teleost ricefield eel (*Monopterus albus*), it was demonstrated that androgens rather than estrogens are responsible for the expression of *cyp19a1b* in the brain through an androgen responsive element (Zhang et al., 2012). It is likely that for the fish, the result is the same,

i.e. a high expression of aromatase B in the brain when steroid circulating levels are high, causing elevated estrogen production in the brain of mature fish.

Little is known on the potential function of estrogen produced in radial glial cells. Knocking down the *cyp19a1b* gene in zebrafish has no impact on sexual differentiation whereas the lack of *cyp19a1a* causes impairment of female sexual differentiation and delay in male sexual differentiation (Yin et al., 2017). However, the potential role on brain sexual differentiation or sexual behavior has not been studied. Still in zebrafish, it was shown that blocking estrogen synthesis with aromatase inhibitors or blocking estrogen receptors with estrogen receptor antagonists causes inhibition of RGC proliferation and newly formed cell migration (Diotel et al., 2013). Exposing larvae to estrogens has similar effects, but the overall impact on brain development has not been studied. In mammals, at least in rodents, aromatase is involved in the permanent brain sexual differentiation, but there is no such information in fishes where it is believed that the brain is not permanently sexualized as fish can naturally or experimentally switch from male to female sexual behavior. One possibility is that, given that fish generally do not perform somatic growth and gonadal growth at the same time, high circulating sex steroids may inhibit neurogenesis at a time when energy needs to be channeled towards the gonads. However, this hypothesis has not been challenged. Thus, so far the unique features of *cyp19a1b* expression in radial glial cells and its sensitivity to estrogens and androgens have not received any final explanation and remain kind of a mystery. In any case, these characteristics have allowed developing a very sensitive *in vivo* screening assay for estrogenic compounds in zebrafish early embryos currently under validation by the OECD as a regulatory test (Brion et al., 2012).

Epilogue: return to the starting point

Today, looking back at the black box, I realize how much progress our scientific community has collectively achieved over these 45 years and, considering the acceleration in the development of new technologies and in the gain of knowledge, I really wonder what the future will look like. Probably, you will fill the black box with many smaller ones that will be opened in turn to find even

smaller ones, just like Russian dolls. As for me, I had to retire in 2016 since, in France, there is a legal retirement age for the scientists and thus I am now a CNRS emeritus research director. I live in a small village located half way between Bordeaux and Toulouse, but I still have a lot of science-related activities, which keep me quite busy. Nevertheless, I have enough time to remember the (mostly) good memories I keep from my 45 years of research in the field of comparative endocrinology. This is a very nice and stimulating community so that, if I had to do it to again, I don't think I would change anything. Not only being paid for creating knowledge is a blessing, but also the opportunity to meet all those senior scientists or students from all over the world is something enviable. I did a lot of work in collaboration with all sorts of people coming from everywhere, many of which became friends. I never had to regret it, on the contrary it was an invaluable enrichment. But, the best part of the job was being in the lab with my students and young collaborators looking at and interpreting what was under the microscope. They are too many to be listed here, but I want to express my gratitude to all my collaborators, students, post-docs and visiting scientists (Figures 3-8) that made my everyday life so rich and exciting. I cannot finish without mentioning my dear wife Sylvaine who never complained about the many collaborators who enjoyed her excellent hospitality and cuisine. Without her support, life would have been much more difficult.

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Legends to Figures

Figure 1: Dick Peter's laboratory in June 1980. From left to right: Lin Haoran, "Wegee" Garcia, Richard E. Peter, Murray Wiegand, Ann Kyle, Duncan and Phyllis MacKenzie, Norman Stacey. The picture was taken in Banff (Canada).

Figure 2: Professor André Calas together with Rabia Magoul and Olivier Kah at a meeting in Marrakech (Morocco).

Figure 3: Evaristo Mañanos, Olivier Kah, Manuel Carrillo, José-Antonio Muñoz-Cueto and Francisco Pratt attending the 5th International Symposium on Reproductive Physiology of Fish in 1995 in Austin (Texas, USA).

Figure 4: Olivier Kah's team in 2010. Left to right: María Rita Pérez, Medjda Bellrami , Isabelle Anglade, Yann Le Page, Santosh Winkins, Olivier Kah, Fabrice Senger, Nicolas Diotel, Sebastian Escobar, Svetlana Mironov, Yohann Mérot, Elisabeth Pellegrini, Marie-Hélène Marmignon. Foreground; Marie-Madeleine Gueguen, Colette Vaillant, Arianna Servili.

Figure 5: The magic team that organised the Congress of European Comparative Endocrinologists in Rennes in 2014. First row: Alba Quesada, Lina Chouchene, Aida Sanchez-Bretaño, Olivier Kah, Clémentine, Yann Le Page, Santosh Winkins, Yohann Mérot, Colette Vaillant, Joel Cano-Nicolau, Patricia Rousseau, Pascal Coumailleau.

Figure 6: Jack Falcón, José-Antonio Muñoz-Cueto, Silvia Zanuy at a meeting in Marrakech (Morocco).

Figure 7: Gustavo Somoza, Vance Trudeau, Olivier Kah and Rüdiger Schulz at the 8ISFE in Gothenburg in 2015 (Sweden).

Figure 8: Francesc Piferrer and Ching-Fong Chang having a discussion during the 8th International Symposium on Reproductive Physiology of Fish in 2007 in Saint-Malo (France).

Highlight

This article summarizes the scientific itinerary of Professor Olivier Kah between 1975 until 2019. In particular, it highlights his main contributions in the overall scientific context of the time and insists on the major steps of his scientific itinerary and the important choices that had a major impact on his career. It also highlights a number of mentors and collaborators who have influenced his technical and conceptual choices.